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A TRANSISTORIZED PSEUDO-RANDOM NOISE GENERATOR

DECEMBER 1962

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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A TRANSISTORIZED PSEUDO-RANDOM NOISE GENERATOR

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ABSTRACT: A stable, transistorized pseudo-random noise generator was designed and developed to operate on a minimum amount of power. It employed a shift register, a coincidence detector, and a clock generator in its operation. The report makes a brief comparison between the characteristics of real noise and pseudo-random noise and discusses the operation of the various electronic circuits comprising the generator.

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PHYSICS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

This report describes the development of circuits for a laboratory pseudo-random noise generator which should have wide use wherever a reproducible time function is needed having properties similar to random noise. This work was performed under Task Number NOL-396, Applied Research. The information in this report will be of interest to scientists who wish to design or use pseudo-random noise generators.

R. E. ODENING
Captain, USN
Commander

Zaka I. Slawsky
Z. I. SLAWSKY
By direction

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A TRANSISTORIZED PSEUDO-RANDOM NOISE GENERATOR

INTRODUCTION

1. This report describes the development of a very stable, compact transistorized pseudo-random noise generator. The chief advantages of this generator over a vacuum tube version are its extremely low power drain, low weight, portability, and compactness. The fact, that two small batteries supply all the power needed to operate it, makes it a useful instrument for both laboratory and field work. In addition the generator is crystal-controlled to provide a high degree of frequency stability (1 part in 10^6).

2. Pseudo-random noise makes an interesting and useful signal for both experimental and military applications. Since it appears to be random in nature, it is difficult for an enemy to detect or jam. At the same time its wide-band power spectrum and its reproducibility by the user provide an easily detectable signal capable of high information transmission rates. In correlation and propagation studies, it has the same advantages that pulse measurements have over discrete frequencies in that precise delay measurements can be made. Arrivals by several paths can be easily separated. The waveform of the signal produced by this generator is a series of constant amplitude rectangular pulses which are time modulated in an apparently random fashion. When this signal is passed through a band-pass filter, its appearance is altered to resemble Gaussian noise.

PROPERTIES OF NOISE

3. Random Noise. Noise has many definitions depending upon the field in which one is working. In the field of communications, noise is generally defined as an electrical disturbance which has a quality of randomness in its character. In Gaussian noise, for example, the instantaneous amplitudes of the disturbance (electrical or otherwise) conform to the "normal" or Gaussian probability law of distribution. The term random indicates a lack of predictability or a lack of periodicity in the signal. This in turn implies a power spectrum (defined in the next paragraph) that is a continuous function containing no lines or discrete frequencies.

4. Two important mathematical relationships, which are useful for describing non-random functions, are also convenient tools for describing random signals or noise. They are the power spectrum $G(\omega)$ and the autocorrelation function $\Psi(\tau)$. The power

spectrum is defined as the power distribution function of a signal over a frequency band from $-\infty$ to $+\infty$. More explicitly it may be thought of as the power dissipated in a unit load for each unit of angular frequency ω. The power spectrum describes a signal in the frequency domain. The autocorrelation function contains the same information but describes a signal in the time domain. It is defined by the equation

$$\gamma(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} A(t) \cdot A(t + \tau)\, dt \tag{1}$$

where $A(t)$ represents the signal amplitude as a function of time t, τ is a time delay, and T is a very long period of time. The autocorrelation function and the power spectrum are related to each other by the Wiener-Khintchine equations.

$$\gamma(\tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{j\omega\tau}\, G(\omega)\, d\omega \tag{2}$$

and

$$G(\omega) = \int_{-\infty}^{\infty} e^{-j\omega\tau}\, \gamma(\tau)\, d\tau \tag{3}$$

which show that either function is the Fourier transform of the other. Since they both contain the same information, the choice of one over the other to describe a signal is governed by the convenience afforded in a specific application.

5. Pseudo-Random Noise. Any type of predictable signal or disturbance, which appears to a casual observer to have a random quality, may be called a pseudo-random noise. The particular type of signal discussed in this report and produced by the subject generator fits such a description. The signal has an infinite band-width whose time function appears as a long series of constant amplitude pulses with apparently randomly distributed widths. The widths actually are predetermined by the generator, and a definite sequence of apparent random widths can be made to repeat at regular intervals of time. This repetition period can be increased practically indefinitely in length by the proper choice of generator parameters so that the pseudo-random noise can be made to approach pure noise in character. A pure noise might be thought of as a time sequence of infinite period in contrast to pseudo-random noise which has a finite period.

6. Characteristics of Pseudo-Random Noise. A plot of the autocorrelation function of pseudo-random noise of the type discussed in this report is shown in Figure 1. A peak occurs at regular intervals of time equal to the repetition period P of the pseudo-

random noise signal. As this period increases, the peaks get farther apart. When the period approaches infinity, the autocorrelation function reduces to a single peak which is characteristic of true noise. This function may be described mathematically by

$$\psi(\tau) = 1 - \frac{|\tau|}{t_o}, \qquad |\tau| < t_o \tag{5}$$

$$\psi(\tau) = 0 , \qquad |\tau| > t_o \tag{6}$$

where τ is the time delay and t_o is the clock period or the smallest pulse width.

7. The Fourier cosine transform of the autocorrelation function of a single peak gives the equation of the power spectrum of a true random noise. This yields

$$G(f) = \frac{1}{f_o} \frac{\sin^2 \frac{\pi f}{f_o}}{\left(\frac{\pi f}{f_o}\right)^2} \tag{7}$$

where f_o is the clock frequency and f represents the frequencies in the spectrum. A plot of this equation is shown in Figure 2. It is evident from this that although the spectrum is infinitely wide, the majority of the spectral energy lies in a band of frequencies below the clock frequency f_o. Therefore to spread the energy out over a wide band requires making the clock frequency as large as possible. Since pseudo-random noise has a repetition period, it will not have a continuous power spectrum as shown. Instead it will have a line spectrum whose envelope will be identical to the continuous spectrum. The separation of these lines will occur 1/P cycles apart over the entire spectrum. It is obvious therefore that as P increases, the lines get closer together and finally merge as a continuous spectrum, or true noise, as P approaches infinity. A short section of pseudo-random noise as a time sequence is shown compared to Gaussian noise in the oscillograms of Figure 3. In the bottom of Fig. 3(a) the waveform of wide-band pseudo-random noise is shown as it appears when unfiltered. The vertical sides of the rectangular pulses, which make up the pseudo-random noise signal, do not show up in the photograph because of the rapid switching action. Just above this, the same section of signal is shown after it has been filtered by an octave band-pass filter. The similarity between Gaussian noise and pseudo-random noise is demonstrated by Fig. 3(b) where the oscillogram of wide-band Gaussian noise is shown after having been passed through the same octave filter. The preceding discussion was introduced to show similarities and differences between true random noise and pseudo-random noise.

CIRCUIT DESCRIPTION

8. Operation of the Pseudo-Random Noise Generator. Pseudo-random noise can be produced in many different ways. The method employed by the generator discussed in this report can be understood by examining the block diagram of the complete pseudo-random noise generator shown in Figure 4. It consists of three basic parts: a clock generator, a shift register and a coincidence detector. The clock generator is essentially a pulse generator which furnishes pulses to the shift register at a constant repetition rate. The shift register consists of ten stages of flip-flops which serve as memory units. Each stage maintains the information stored in it until a clock pulse is received, at which time it shifts its information to the following stage on the right. The coincidence detector compares the information in two selected stages (No. 7 and No. 10 in this case) and feeds new information based on this comparison to the input stage at the occurrence of each clock pulse. The information in each stage is in the form of binary digits. Thus a binary digit that is fed into Stage No. 1 from the coincidence detector will be shifted consecutively through each stage finally arriving at Stage No. 10 after which it is discarded. At any interval of time between clock pulses, the information in all ten stages represents a binary number of ten digits. With n stages it is therefore possible to represent any one of 2^n numbers. By connecting the coincidence detector to the proper two stages, it can be shown that the shift register will set up consecutively every possible number from zero to 2^n-1 in an apparent random order. A new number is set up with the generation of each clock pulse. A time sequence containing all these possible binary numbers represents the maximum period or the lowest repetition frequency of the generator. This period is given by

$$T = \frac{2^n - 1}{f_o} = (2^n - 1)\, t_o \qquad (8)$$

where f_o is the clock frequency and t_o is the clock period. the "-1" enters the picture because the generator inherently will not set up the binary number containing all "ones". If it did, the coincidence detector would feed nothing but "ones" to the input stage and the system would be blocked. It is also characteristic of this type of generator that if the wrong two stages are compared, the generator will run through a shorter and different sequence by omitting some of the possible numbers and rearranging those that are included. It is also possible to compare other stages with Stage No. 10 to obtain a full sequence and a different order.

9. The subject generator has ten stages and a 50 ms period so

that Eq. (8) fixes the clock frequency at 20,460 cps. A voltage representing the pseudo-random noise signal may be taken off any one of the stages, since the same signal is shifted through the entire set of ten stages. In this respect the shift register behaves like a tapped delay line since the signal experiences a time delay of t_o for each stage, or a total delay of $10t_o$ for the entire register. If the binary digit "one" is in the output stage, an electrical voltage corresponding to the top of the rectangular pulse is obtained, while if the digit "zero" is present, a low voltage corresponding to the bottom of the pulse is produced. The width of the output pulse is determined by the number of successive "ones" appearing in the stage, while the pulse spacing is determined by the successive number of "zeroes". It is evident that the width of the narrowest pulse is the time duration of a single digit "one" in the output stage, which is equal to the period of the clock frequency. Other pulse widths occurring in the pseudo-random noise will be integral multiples of the clock period with the widest pulse having a width of $t_m = (n-1)t_o$. The distribution of different pulse widths are such that the digit "one" appears in the output $\frac{2^n-1}{2}$ times, while the digit "zero" appears $\frac{2^n}{2}$ times during one complete sequence, that is to say, each digit appears essentially 50% of the time.

10. Shift Register. The circuit diagram of the memory unit which makes up each stage of the shift register is shown in Figure 5. It is basically a bi-stable multivibrator, a flip-flop, which remains in one of its two conducting states indefinitely until it is changed by an input signal. The output terminals are indicated by A and B and are hooked to the input of the following stage. The two diodes forming the input to the bases of the transistors are connected to the preceding stage by terminals C and D. The diodes serve to direct the clock pulses to the proper base to make the unit assume the same state as the preceding stage. This is accomplished in the following manner. Being connected to opposite sides of the preceding flip-flop, the two diodes have voltages applied to themselves so that one is biased several volts beyond cut-off while the other is biased near conduction. The clock pulse, which is impressed equally on the two diodes, is large enough in amplitude to drive the second of the above diodes into conduction but is too small to drive the over-biased one to conduction. Only the conducting diode allows the clock pulse to reach the base of its transistor. The inter-stage connections are such that the proper diode will conduct to make the flip-flop in question assume the same state as the preceding stage. The considerations used in the design of this unit were to minimize the power requirements while maintaining the switching speed high enough above the clocking frequency.

to assure reliability.

11. The output signal of the pseudo-random noise generator may be taken off of a collector of any one of the flip-flop stages of the shift register. An emitter follower stage, whose circuit is shown in Figure 6, is used to isolate the shift register from the external load.

12. Coincidence Detector. The circuit diagram of the coincidence detector is shown in Figure 7. It is composed of two "and" circuits and one "or" circuit connected to a Schmitt trigger. This "and" circuit composed of two diodes and a resistor gives a negative output voltage when both of its inputs are negative. All other input conditions produce a positive output so that an "and" circuit is essentially a binary multiplier. One "and" circuit will thus indicate negative coincidence at its input but will not indicate positive coincidence. It is therefore necessary to have a second "and" circuit connected to the same stages as the first but hooked to opposite sides where the signals are 180° out of phase with those going into the first "and" circuit. The second "and" circuit then will provide a negative output signal when both of the original signals are positive. The outputs of the two "and" circuits are then added by the "or" circuit to provide a signal which will indicate both positive and negative coincidences. The "or" circuit supplies the Schmitt trigger with a driving voltage to maintain it in one of its two stable states. Besides serving as a buffer for the coincidence detector, the trigger also provides the input of Stage No. 1 with the same electrical conditions as that presented to the input of the other stages. Stage No. 1 will then assume the same state as the Schmitt trigger at the occurrence of each clock pulse.

13. Clock Generator. The circuit diagram of the clock generator which controls all these operations is shown in Figure 8. The oscillator portion is essentially an astable multivibrator whose repetition frequency is accurately controlled by a crystal at 20.46 kc. The temperature of the crystal is not controlled by an oven but by a small amount of thermal insulation which provided a signal with a drift rate of less than 0.01 cps per hour. In certain experimental applications where a fixed clock frequency is not desired, a stable variable frequency oscillator, as described in Reference (1), may be substituted for the crystal oscillator used here. An emitter follower serves as a buffer between the oscillator and shaper. The latter transforms the oscillator signal to a series of positive pulses which are suitable for driving the shift register. And finally an emitter follower is used in the output stage to provide the necessary power gain required to drive all the stages of the shift register.

SUMMARY

14. Conclusions. The character and some of the properties of true random noise were reviewed in the above discussion and then compared with the properties of pseudo-random noise. Next the design and operation of a practical pseudo-random noise generator were described. This generator is characterized by portability, compactness, light weight, high stability, and low power requirements. It was constructed on three printed-circuit boards, each 6" x 7" in size. The first board contained the clock generator and several output emitter followers; the second board held the Schmitt trigger and the first five stages of the shift register; and the third board held the five final stages of the shift register and the coincidence detector. All three boards and the power supply batteries were housed in a small metal utility cabinet. The total power drain of the noise generator was less than 90 milliwatts. The generator has already found many applications in coherency studies and information transmission experiments, Reference (2). There are potential uses for this generator in many other areas such as correlation and propagation studies in underwater acoustics.

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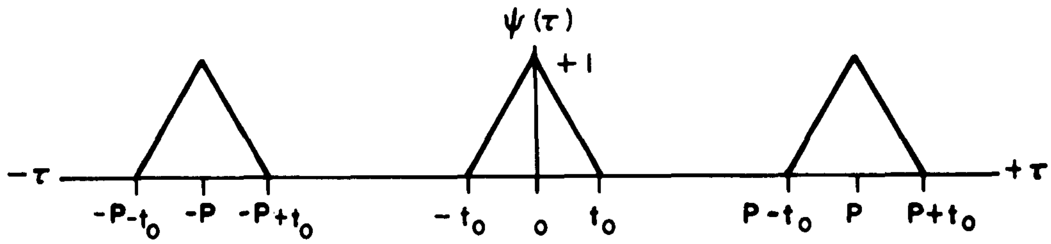

FIG. 1 THE AUTOCORRELATION FUNCTION OF A PSEUDO-RANDOM NOISE

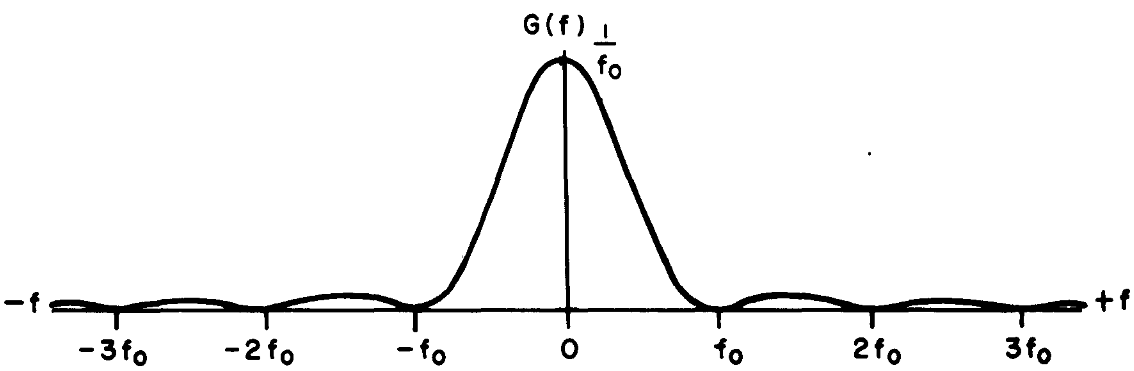

FIG. 2 THE POWER SPECTRUM OF A RANDOM NOISE THAT CONSISTS OF CONSTANT AMPLITUDE PULSES OF RANDOMLY VARYING WIDTHS

(a) PSEUDO-RANDOM NOISE, FILTERED AND BROAD-BAND

(b) FILTERED GAUSSIAN NOISE

FIG. 3 OSCILLOGRAMS COMPARING PSEUDO-RANDOM AND GAUSSIAN NOISE

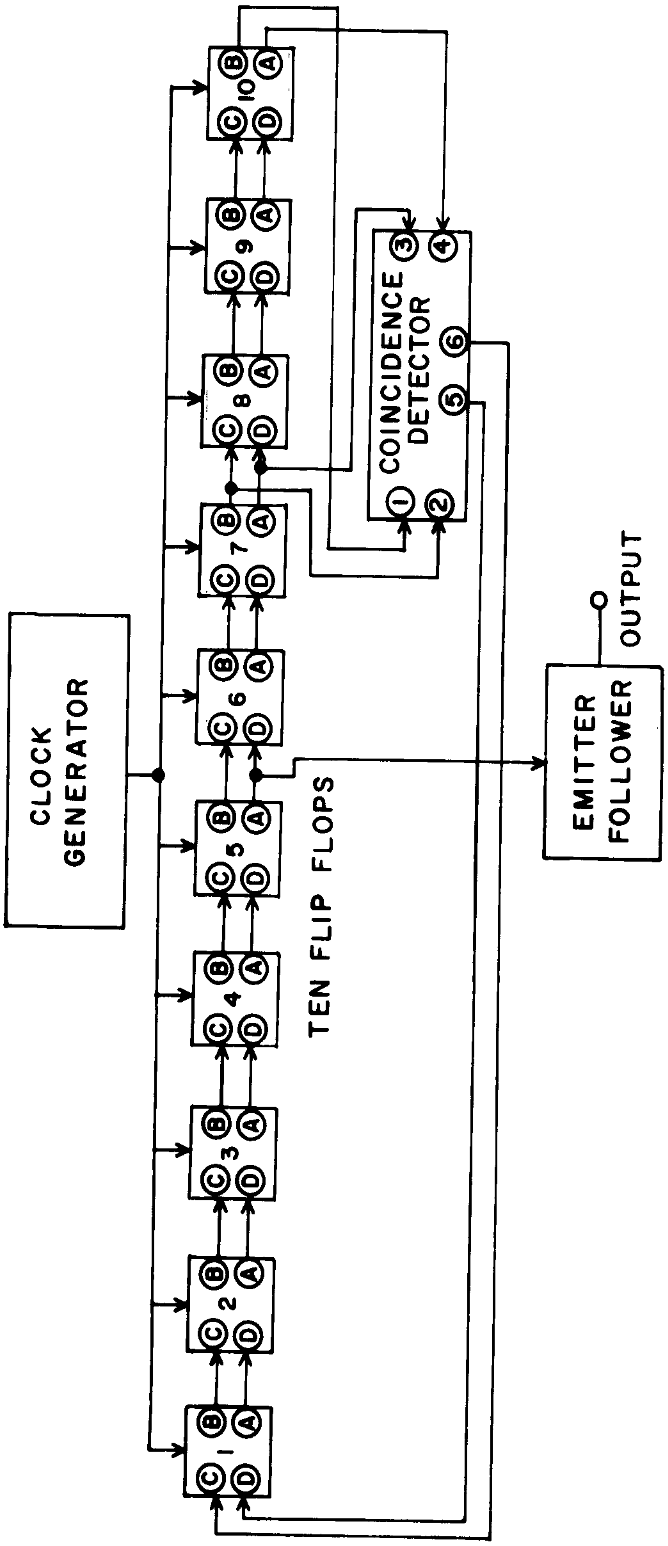

FIG. 4 BLOCK DIAGRAM OF A TRANSISTORIZED PSEUDO-RANDOM NOISE GENERATOR

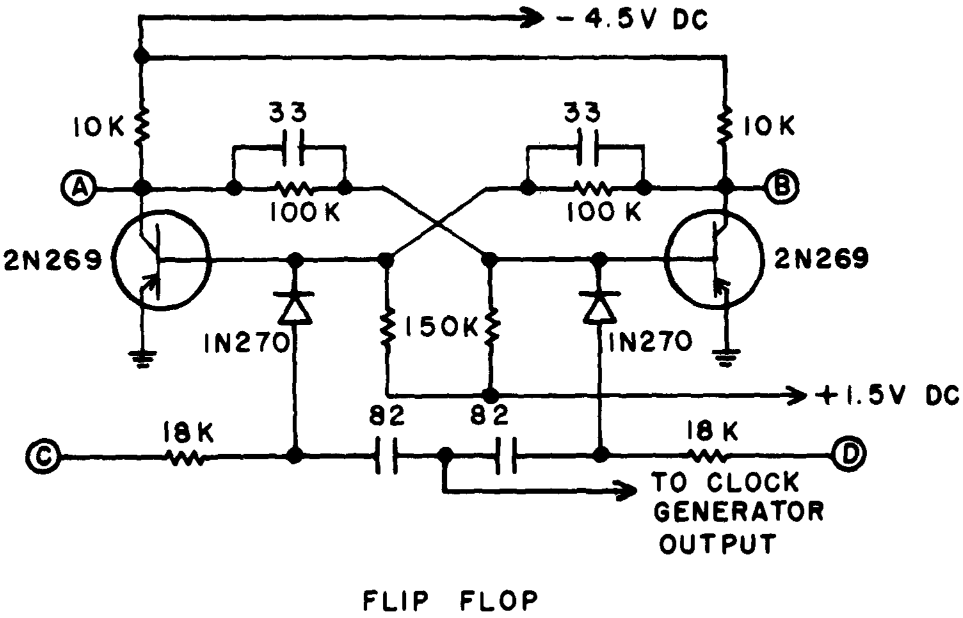

FIG.5 CIRCUIT DIAGRAM OF ONE STAGE OF THE SHIFT REGISTER

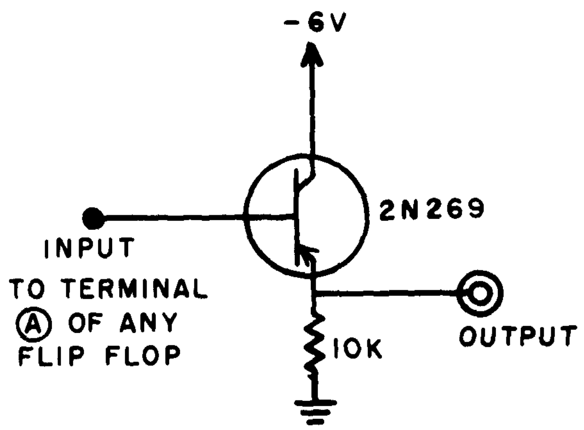

FIG.6 CIRCUIT DIAGRAM OF THE EMITTER FOLLOWER

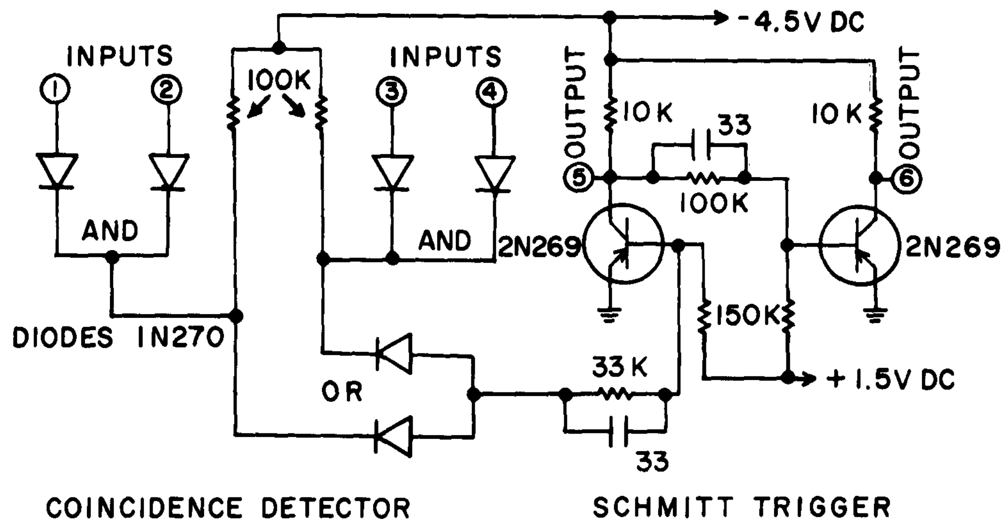

FIG.7 CIRCUIT DIAGRAM OF THE COINCIDENCE DETECTOR AND TRIGGER

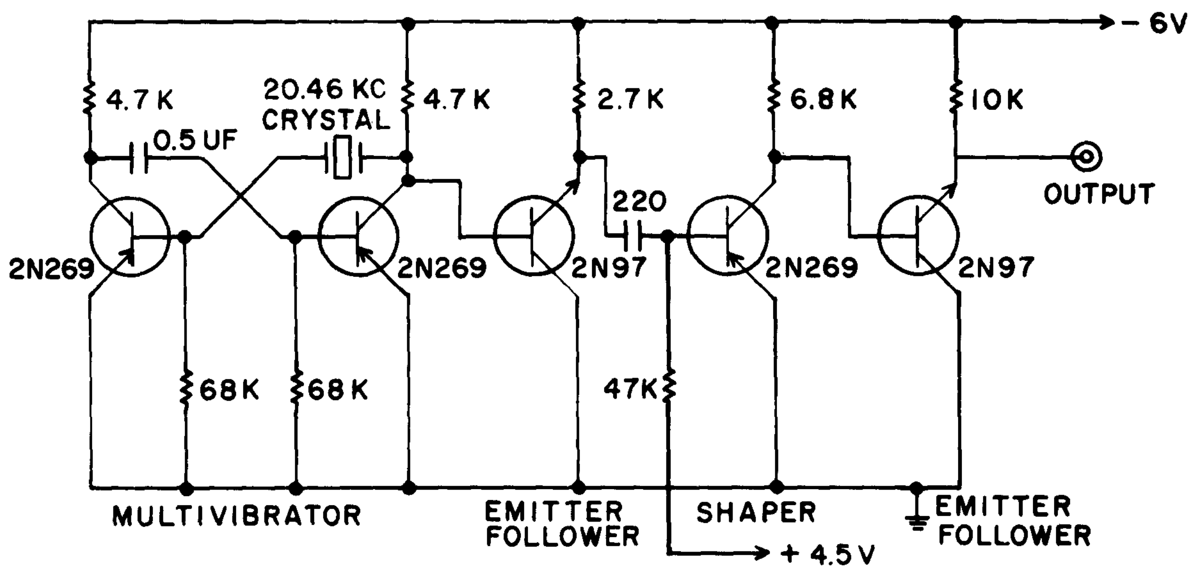

FIG. 8 CIRCUIT DIAGRAM OF THE CLOCK GENERATOR

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SUBJECT ANALYSIS OF REPORT

DESCRIPTORS	CODES	DESCRIPTORS	CODES	DESCRIPTORS	CODES
Pseudo	PSEU	Electronic	ELCO		
Random	RAND	Circuits	CIRC		
Acoustic	ACOU	Circuits (Design)	CIRCD		
Generator	GENR	Circuits (Operation)	CIRCI		
Transistorized	TRNT				
Shift	SHIF				
Register	REGI				
Coincidence	COIN				
Detector	DETT				
Clock	CLOC				
Noise	NOIS				
Noise (Properties)	NOISP				

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A TRANSISTORIZED PSEUDO-RANDOM NOISE GENERATOR (U), by K. G. Williams. Dec. 1962. 12p. charts. Task NOL 396. UNCLASSIFIED

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Abstract card is unclassified.

1. Generators, Sound
2. Generators, Transistorized
3. Generators - Circuits
4. Registers, Shift
5. Detectors, Coincidence
6. Generators, Clock

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III. Project

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